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Research paper

Last glacial period cryptotephra deposits in an eastern North Atlantic marine sequence: Exploring linkages to the Greenland ice-cores

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ABSTRACT

The establishment of a tephra framework for the Greenland ice-cores spanning the last glacial period, particularly between 25 and 45 ka b2k, provides strong potential for precisely correlating other palaeoclimatic records to these key archives. Tephra-based synchronisation allows the relative timing of past climatic changes recorded within different depositional environments and potential causal mechanisms to be assessed. Recent studies of North Atlantic marine records have demonstrated the potential of tracing cryptotephra horizons in these sequences and the development of protocols now allows a careful assessment of the isochronous nature of such horizons. Here we report on tephrochronological investigations of a marine sequence retrieved from the Goban Spur, Eastern North Atlantic, covering ~25–60 ka b2k. Density and magnetic separation techniques and an assessment of potential transport and depositional mechanisms have identified three previously unknown isochronous tephra horizons along with deposits of the widespread North Atlantic Ash Zone II and Faroe Marine Ash Zone III. Correlations between the new horizons and the Greenland ice-core tephra framework are explored and despite no tie-lines being identified the key roles that high-resolution climatostratigraphy and shard-specific trace element analysis can play within the assessment of correlations is demonstrated. The previously unknown horizons are new additions to the overall North Atlantic tephra framework for the last glacial period and could be key horizons for future correlations.

1. Introduction

The tracing of isochronous horizons of volcanic ash between different depositional realms (tephrochronology) has considerable potential for the independent correlation and synchronisation of disparate palaeoclimatic sequences and for assessing the relative timing of past climatic events (Lowe, 2011). The potential of tephrochronology to assess these relative timings is especially pertinent for the last glacial period as there is evidence for several abrupt climatic changes preserved within ice-cores from Greenland (e.g. GRIP Members, 1993; Johnsen et al., 2001; NGRIP Members, 2004) and numerous North Atlantic marine cores (e.g. Bond et al., 1993, 1997; Van Kreveld et al., 2000; Martrat et al., 2007; Hall et al., 2011; Zumaque et al., 2012).

A large number of tephra horizons have been identified within multiple Greenland ice-cores spanning the last glacial period (Abbott and Davies, 2012; Bourne et al., 2013, 2015b; Davies et al., 2014). Bourne et al. (2015b) in particular increased the number of horizons identified in the NGRIP, NEEM, GRIP and DYE-3 ice-cores and, in combination with past studies, a framework of 99 geochemically characterised tephra deposits has now been defined for the 25–45 ka b2k period. Developing a framework of geochemically characterised horizons with strong stratigraphic and chronological control is an essential first step towards the synchronisation of these records to other palaeoclimatic sequences in a range of environments. A notable feature of the ice-core framework is the dominance of deposits, closely spaced in time, that have similar major element compositions relating to single sources, e.g. the Icelandic Grímsvötn volcanic system. Subtle major element differences can be used to discriminate between some deposits, but others have major element compositions which are indistinguishable (e.g. Bourne et al., 2013).

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This compositional similarity presents a challenge when attempting to correlate tephra horizons from sequences with limited chronological and/or stratigraphic control. In these instances it has been widely advocated that any available climatostratigraphic evidence can be used alongside the compositional data to narrow down potential correlatives (e.g. Newnham and Lowe, 1999; Newnham et al., 2004; Pearce et al., 2008; Housley et al., 2012; MacLeod et al., 2015) and that trace element analysis of the tephra deposits may provide a useful secondary compositional fingerprint for testing and assessing the robustness of correlations (e.g. Allan et al., 2008; Abbott et al., 2012, 2014; Albert et al., 2012; Lane et al., 2012; Bramham-Law et al., 2013; Pearce et al., 2014; Bourne et al., 2015a).

Overall, there is an order of magnitude difference between the number of tephra horizons identified in the Greenland ice-cores and North Atlantic marine sequences between 25 and 60 ka b2k. Only a few marine records have been investigated for their tephra content and there is a tendency to focus on visible horizons or on the coarse-grained components (>150 μm) (e.g. Lackschewitz and Wallrabe-Adams, 1997; Wastegård and Rasmussen, 2014). As a result, only two ice-marine tie-lines have been defined within the last glacial period. Firstly, the rhyolitic component of the widespread North Atlantic Ash Zone (NAAZ) II (55,380 ± 1184 a b2k; Svensson et al., 2008) has been traced within multiple ice and marine cores (e.g. Kvamme et al., 1989; Grönvold et al., 1995; Lacasse et al., 1996; Zielinski et al., 1997; Haflidason et al., 2000; Austin et al., 2004). Secondly, Faroe Marine Ash Zone (FMAZ) II, a visible horizon identified in a number of marine cores from the Faroe Islands region (Wastegård et al., 2006), was traced into the NGRIP ice-core by Davies et al. (2008) (NGRIP 1848 m; 26,740 ± 390 a b2k). A third ice-marine correlation was also proposed between the NGRIP 2066.95 m horizon (38,122 ± 723 a b2k) and FMAZ III, a thick and relatively scattered zone of glass shards traced between a number of the Faroe Islands region cores (Wastegård et al., 2006; Davies et al., 2010). However, Bourne et al. (2013) later highlighted the complexity of this period and identified a series of closely spaced tephra horizons with similar glass compositions in the NGRIP and NEEM ice-cores. Their compositions all fall within the broad compositional envelope of FMAZ III and the marine deposit has been interpreted as resulting from the amalgamation of primary tephra-fall from a number of volcanic events as a consequence of low sedimentation rates at the marine core sites (Bourne et al., 2013; Griggs et al., 2014). Therefore, the prior correlation between FMAZ III and a single tephra layer in the ice-cores is no longer valid and should not be used as an ice-marine tie-line. However, the tephra layers in the ice may still act as tie-lines if individual homogenous horizons from those single events can be found in marine records. This particular example highlights some of the complexities involved with defining correlations between the records.

In recent years, there has been a shift towards the investigation of the cryptotephra record preserved within marine sediments. Density and magnetic separation techniques, previously applied to terrestrial sequences, have recently been successfully used to extract fine-grained cryptotephras, preserved as discrete deposits of glass shards, from a number of cores around the North Atlantic (e.g. Abbott et al., 2011, 2013, 2014; Griggs et al., 2014; Davies et al., 2014). Magnetic separation techniques are particularly important for the identification of basaltic cryptotephras in North Atlantic marine records because of the dominance of basaltic tephra deposits within the Greenland tephra framework (Abbott and Davies, 2012; Bourne et al., 2013, 2015b). In addition to these methodological advances, Griggs et al. (2014) outlined a protocol which uses a range of indicators to determine the potential influence of transportation and depositional processes on the stratigraphic and temporal integrity of marine tephra deposits. To date, these methods and approaches have not been utilised to isolate cryptotephras in North Atlantic marine sequences covering the 25–60 ka b2k period. The Greenland tephra framework in particular, now demonstrates the potential for tephrochronological synchronisation if common horizons can be identified.

Here we report on tephrochronological investigations of the 25–60 ka b2k period within a marine core retrieved from the Goban Spur area in the eastern North Atlantic (MD04-2820CQ). Potential correlations to the Greenland tephra framework are explored with new high-resolution proxy data from MD04-2820CQ used to help determine the stratigraphic position of the tephra horizons and trace element analysis is utilised as a secondary compositional fingerprint.

2. Materials and methods

2.1. MD04-2820CQ

MD04-2820CQ was retrieved from the Goban Spur area (49°05.29′N; 13°25.90′W; Fig. 1) and is a reoccupation of the OMEX-2K core site (see Hall and McCave, 1998a,b; Scourse et al., 2000; Haapaniemi et al., 2010). A Ca XRF record and a low-resolution record of the percentage abundance of the polar foraminiferal species *Neogloboquadrina pachyderma* (sinistral) (*Np*(s)) have been used to define a preliminary stratigraphy for the sequence between MIS 3-2. A number of Dansgaard-Oeschger events related to the Greenland Interstadial (GI) events in the Greenland ice-cores are recognised within this record (Fig. 2; Rasmussen et al., 2014). Between 450 and 550 cm depth, high-resolution (up to 1 cm) records of *Np*(s) and ice rafted debris (IRD) concentrations (150 μm^{-1} mm fraction) were generated to provide a more detailed stratigraphy between DO-12 and DO-8 to help constrain the tephra deposits within a climatic framework (Fig. 6).

The tephra content of the core was initially investigated at a low-resolution (5 cm contiguous samples) between 250 and 650 cm depth. Intervals with distinct peaks in glass shard content above background levels were subsequently re-investigated at 1 cm resolution to refine their stratigraphic position (Fig. 2).

2.2. Extraction of tephra-derived glass shards from marine sequences

From the 5 and 1 cm samples, 0.5 g sub-samples of freeze-dried marine sediments were immersed in 10% HCl overnight to remove carbonate material. Samples were then wet sieved using 125 and 80 μm test sieves and 25 μm nylon mesh. The 25–80 μm fraction was then density separated using sodium polytungstate prepared to the specific gravities of 2.3 and 2.5 g/cm^3 to split the material into the density fractions of <2.3 g/cm^3, to remove biogenic material, 2.3–2.5 g/cm^3, to isolate rhyolitic material, and >2.5 g/cm^3 to isolate basaltic material (Turney, 1998). To further purify the >2.5 g/cm^3 fraction it was magnetically separated using a Frantz Isodynamic Magnetic Separator. The methodology and conditions for magnetic separation are outlined in Griggs et al. (2014) and allow the separation of non-magnetic quartz material from any paramagnetic basaltic material. The >125 μm and 80–125 μm grain-size fractions, and the 2.3–2.5 g/cm^3 and magnetic >2.5 g/cm^3 density fractions, were mounted on microscope slides in Canada Balsam for optical microscopy to quantify their glass shard content.

2.3. Geochemical analysis of individual glass shards

Samples for geochemical analysis were prepared using the